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Protocol for the energy behaviour assessment of social housing stock: the case of southern Europe.

Rocío Escandón[a,]*, Rafael Suárez[a], Juan José Sendra[a]

[a]*Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Av. de Reina Mercedes 2, Seville (41012), Spain.*

Abstract

The aim of recent European Directives and Regulations is the establishment of a common framework for increasing energy efficiency, encouraging the retrofitting of existing housing stock, obsolete in energy terms. Most of the studies carried out on the energy characterisation of existing housing stock for their subsequent retrofitting focus on climate areas in central and northern Europe, but there are fewer studies for southern Europe. This research was initiated in order to contribute to a better understanding of social housing in southern Europe, specifically southern Spain. A protocol was proposed for the assessment of the end-use energy behaviour of social housing stock, taking into consideration geographical location, building typologies, and morphological and constructive characteristics of the envelopes of this housing stock. This protocol is divided into two different phases: a first phase for a general energy assessment and a second phase for a detailed energy assessment. It aims to provide a general energy behaviour assessment as the first step in the proposal of guidelines and strategies for the energy retrofitting of existing social housing stock. In order to achieve these objectives, the first phase of the proposed protocol includes a typological classification of buildings and a morphological and constructive characterisation of thermal envelopes by construction period. The second phase of the protocol includes onsite data collection on hygrothermal behaviour and energy consumption and generation and validation of energy models in the buildings selected for their subsequent energy simulation and rating. In this study, the first phase of the protocol was applied to five case studies built between 1950 and 1980 in the different climate zones in the south of Spain, with the main conclusion that the existing general high level of demand due to the poor thermal performance of the envelope leads to a very low energy rating.

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Keywords: Housing stock; energy assessment; energy performance; energy retrofitting.

* Corresponding author. Tel.: +3-495-455-7024; fax: +3-495-455-7024.
E-mail address: rescandon@us.es

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1. Introduction

The most significant urban growth in major Spanish cities took place between 1939 and 1980, when over 50% of 20th-century residential units were built [1]. In the case of Andalusia, the most important period of urban growth was after 1950. The residential stock built between 1950 and 1980 accounts for 40% of the total built during the 20th century [1]. These data reflect the high percentage of dwellings built with no general guidelines on thermal regulation, given that the Basic Building Standard "Thermal Conditions in Buildings" (NBE CT 79 [2]) was not implemented in Spain until 1979. There is therefore an extensive housing stock that is not subject to specific thermal insulation measures, much of which does not meet current energy standards. The energy assessment and retrofitting of this housing stock, particularly social housing, is therefore necessary. Aware of the importance of investing in retrofitting and the potential of energy savings the different public administrations have incorporated policies as part of the strategies of Horizon 2020. Directive 2012/27/EU [3] and Spanish Royal Decrees RD 233/2013 [4] and RD 235/2013 [5] are a faithful reflection of this.

Most of the studies to date on the energy characterisation of housing stock refer to climate zones in central and northern Europe and Spain [6,7,8,9], although some notable exceptions focus on the southernmost areas of the Mediterranean arch [10,11]. Santamouris worked extensively on the characterisation of environments and energy consumption of social housing stock in Athens, analysing the relationship between low-income families and the quality of the housing they reside in [12,13,14]. Dall'O' [15,16] developed a methodology for the analysis of existing buildings in Italy in order to calculate their energy rating, based on the search for correlations between building characterisation and energy consumption.

When examining the environmental characterisation of a series of residential buildings the studies carried out show that the construction period, building typology, constructive definition of the envelope, and climate zone in which they are located are the four most influential variables for the results obtained [17,18,19].

The aim of this research is to propose a protocol for the assessment of the end-use energy behaviour of social housing stock in climate zones in southern Europe. This assessment is the first step towards the proposal of guidelines and strategies for the energy retrofitting of this social housing stock. The application of this protocol aims to carry out a general study for the south of Spain, characterising energy behaviour by climate zone and focusing on major residential neighbourhoods built between 1950 and 1980.

2. Methodology

A protocol is proposed for the characterisation of the current energy conditions of a large part of the social housing stock of the south of Europe. This protocol is divided into two different phases: the first phase consists in the general assessment of the energy behaviour of residential complexes, while the second provides a detailed energy assessment of the dwellings.

Phase 1 of the protocol, which is applied to the residential complexes in general, is composed of four tasks:

- Task 1.1: Compiling typological, morphological and constructive data on the residential complexes in the sample.
- Task 1.2: Generating energy models for the residential complexes.
- Task 1.3: Simulating energy models for the residential complexes.
- Task 1.4: Discussion of results.

Task 1.1. focused on the statistics and context analysis of social housing stock built in the south of Europe in the period under study, aiming to cover all the climate zones in the region. This research therefore identified and subsequently defined the main social housing developments built in the south of Spain between 1950 and 1980 (the period under study), locating them on a GIS platform (Fig. 1), using QGIS v.2.14.0 software [20]. The necessary information for energy characterisation was uploaded to this platform. The data added were: location, architect, developer, year of construction, number of stories, number of dwellings, building typology, constructed area, original plans, constructive description of envelope, thermal installations and current condition of buildings. For this it was necessary to compile the documentation from the original designs of the sample selected by consulting Municipal Archives as well as bibliography and documents from the archives. The different housing developments were also visited for the assessment of the degree of intervention or decay since construction.

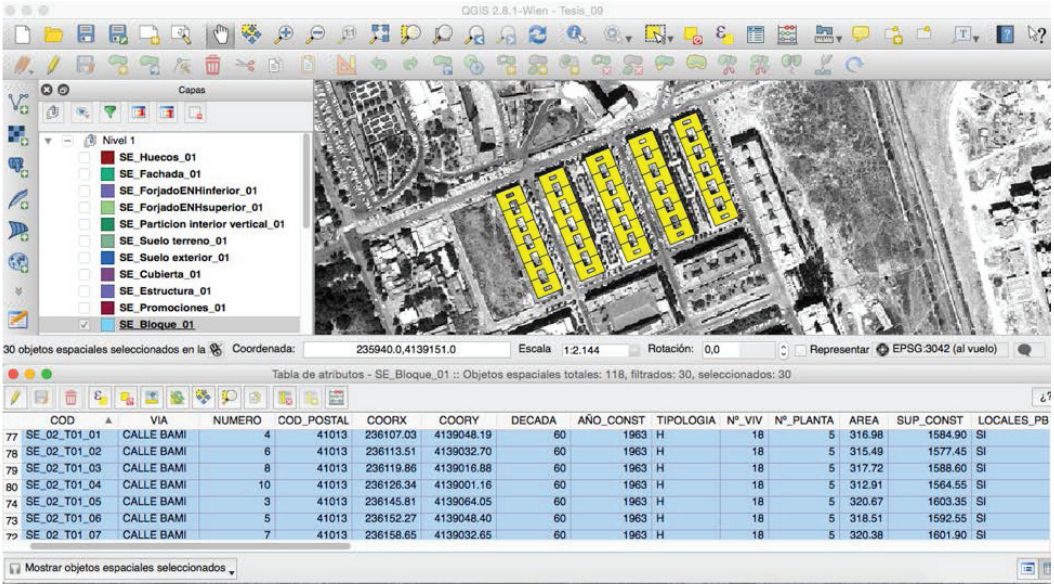

Fig. 1. GIS Platform.

Based on the information compiled during task 1.1. of the protocol, task 1.2, consisting in the generation of energy models of the residential complexes in their original condition, was developed. Prior to the creation of energy models the information needed for the energy analysis was compiled: climate zone, meteorological data, thermal characterisation of envelope, morphological indicators and main thermal installations.

Once the models were generated, task 1.3. was carried out: models simulation using the official simulation tool of each country for the assessment and energy rating of existing buildings. The software used in this case was CE3X v.2.1 [21], an official Spanish tool for the energy rating of existing buildings.

Finally, the data obtained from the model simulation was used to complete task 1.4: the general energy assessment of the residential complexes selected for the case study, analysing energy demand and consumption (heating, cooling and global), as well as the energy rating obtained from the simulation. The results obtained were included in the GIS platform, providing a clear representation of the description and assessment of the current energy, constructive, and social conditions of the housing stock at neighbourhood level.

Phase 2 of the protocol, applied in detail to the dwellings selected for case studies, was made up of four tasks:

- Task 2.1: Monitoring housing units.
- Task 2.2: Generating and validating the energy models of housing units.
- Task 2.3: Simulating energy models for housing units.
- Task 2.4: Discussion of results.

Task 2.1. focused on the onsite measurement of hygrothermal behaviour and energy consumption in the selected case studies. This includes: monitoring environmental conditions (air temperature, relative humidity and level of CO_2 inside and outside the dwellings) using two indoor data loggers (one in the living room and another in the bedroom) and an outdoor meteorological station; monitoring detailed energy consumption in dwellings using a home energy meter and several meters for partial devices; using bills to compile historic data of general electricity and gas consumption; infrared thermography studies of enclosures and pressurisation and depressurisation studies to identify energy loss points in the enclosure and to verify the airtightness of the exterior envelope; and drawing up a survey for residents to obtain accurate information of usage and operation patterns, energy consumption habits and thermal sensation. It is proposed that monitoring tasks have a minimum duration of 9 months (winter, summer and spring or autumn).

The information compiled during task 2.1. of the protocol will be fundamental in executing task 2.2, focusing on the generation and validation of energy models for the monitored dwellings. The first step in the development of these models will be drafting templates for activity, usage, occupation and lighting, relating to the lifestyle of the present residents of the dwellings, based on the survey data. Following this the energy models for the housing units under study will be built and validated. The validation of the model ensured the reproduction of the real energy behaviour of the dwellings under study.

After onsite data collection and the generation and validation of energy models of the housing units, task 2.3. will be developed: the simulation of models using scientifically proven energy simulation tools such as DesignBuilder or similar software. Finally, task 2.4. will be carried out using the data from model simulation, assessing the results, drawing detailed conclusions about end-use energy behaviour of dwellings.

3. Case studies

This research applied the first phase of the protocol described above to five case studies from the most representative climate zones in the south of Spain [22] (Fig. 2): Seville (winter climate zone B, summer climate zone 4), Malaga (A3), Huelva (A4), Granada (C3) and Jaén (C4). These were five multi-family H-shaped blocks, a design which together with linear blocks, is the most common in this region in pre-1980 constructions. The second phase of this protocol is currently being applied in the case studies, although based on a methodology developed by this research group in previous studies [10, 11, 23].

The similarities in typology and construction allow us to compare the results assessing the effect of climate zones on the energy behaviour of models. The five neighbourhoods from the case studies were: Bami in Seville (case 1) (Fig. 3), La Luz in Malaga (case 2) (Fig. 4), El Carmen in Huelva (case 3) (Fig. 5), La Chana in Granada (case 4) (Fig. 6) and Polígono del Valle in Jaén (case 5) (Fig. 7). Table 1 describes the major typological and construction features of the five case studies.

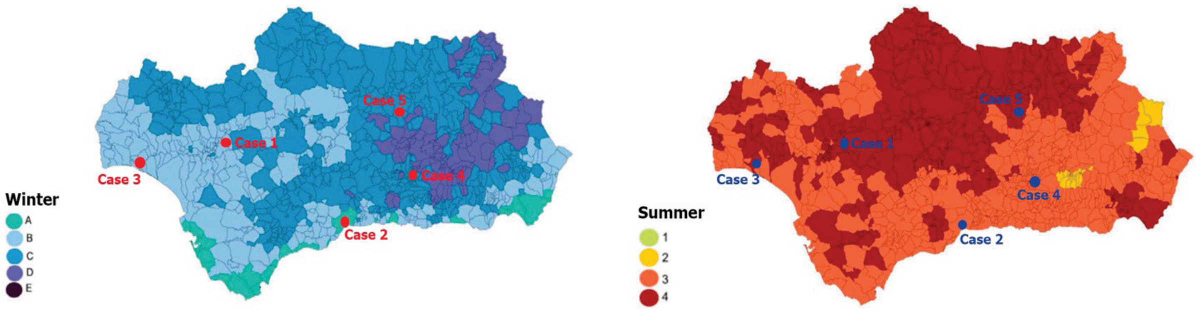

Fig. 2. Climate zones in the south of Spain and case studies location.

Fig. 3. Bami neighbourhood (Seville).

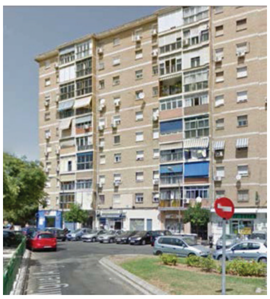

Fig. 4. La Luz neighbourhood (Malaga).

Fig. 5. El Carmen neighbourhood (Huelva).

Fig. 6. La Chana neighbourhood (Granada).

Fig. 7. Polígono del Valle neighbourhood (Jaén).

Table 1. Description of case studies in original condition.

	Case 1 (Seville)	Case 2 (Malaga)	Case 3 (Huelva)	Case 4 (Granada)	Case 5 (Jaén)
Year of construction	1963	1978	1973	1959	1977
Climate zone	B4	A3	A4	C3	C4
Typology	H	H	H	H	H
Orientation of main façades	E-W	SE-NW	E-W	E-W	SE-NW
No. stories	5	10	6	4	8
No. identical blocks	30	90	32	38	27
No. units/block	18	36	24	16	32
Façade	Cement mortar; brick (1 foot); gypsum rendering	Brick (1/2 foot); air chamber; brick (4 cm); gypsum rendering	Cement mortar; brick (1/2 foot); air chamber; brick (4 cm); gypsum rendering	Cement mortar; brick (1 foot); gypsum rendering	Brick (1/2 foot); air chamber; brick (4 cm); gypsum rendering
Façade transmittance (W/m^2K)	1.58	1.69	1.44	1.58	1.69
Type of roof	Flat	Flat	Flat	Sloping	Flat
Roof	Tile; cement mortar; coal dust; ceramic tile; air chamber; roof structure; gypsum rendering	Fibre cement; air chamber; roof structure; gypsum rendering	Tile; cement mortar; concrete; roof structure; gypsum rendering	Roof tile; ceramic tile; air chamber; ceramic tile; gypsum rendering	Fibre cement; air chamber; rockwool; roof structure; gypsum rendering
Roof transmittance (W/m^2K)	1.82	1.88	2.27	1.66	1.06
Joinery	Steel	Steel	Steel	Steel	Steel
Glazing	6 mm	6 mm	6 mm	6 mm	6 mm
Window transmittance (W/m^2K)	5.70	5.70	5.70	5.70	5.70
Solar protection	NO	NO	NO	NO	NO
HW production			Individual butane gas boilers		
Ventilation system (damp units)	Natural through window	Natural through window	Natural through window	Natural through window	Natural through vertical conduct
Heating system			NO		
Cooling system			NO		

4. Results

After compiling and analysing the typological, morphological and constructive data for the case studies (Table 1), the five residential complexes were found to have very similar characteristics, mainly thermal weakness in windows and façades. A series of indicators was obtained (table 2) confirming the morphological similarities between the envelopes of a significant sample of the social housing stock built between 1950 and 1980 in southern Spain. The major differences are found in the percentages for the roof and façade of cases 2 and 5, blocks which have a higher number of stories.

Based on the data collected, energy simulations were carried out for the case studies, analysing their energy demand and consumption and comparing them to the stipulations included in current Spanish regulations: the Technical Building Code (CTE) [24]. Energy demand is defined as the necessary energy (heating and cooling) to maintain the internal conditions of comfort according to the Spanish regulations (CTE). While energy consumption is the non-renewable primary energy estimated to be consumed (for heating, cooling and hot water), considering the standard efficiency of thermal production equipment (established by the Spanish regulations (CTE) for existing buildings). As is to be expected, it has been observed that the energy behaviour of the housing units is far from meeting current regulations (Fig. 8, Table 3), as they were built before the implementation of the first general guidelines on thermal regulation in Spain (NBE CT 79 [2]) (Table 1) in 1979.

The demand for heating in the buildings analysed is very unequal, albeit high in all cases, as a result of the poor thermal performance of the envelope due to poor thermal insulation. Cases 4 and 5, located in the most severe climate zones in the winter (catalogued under letter C) reach a heating demand of at least 90 kWh/m^2, roughly five times the limit of the values established by the CTE. Heating demand is 10 kWh/m^2 higher in case 5 than in case 4, although both are catalogued by the CTE with the same climate severity in winter. This is mainly due to the fact that the percentage of openings in case 5 is slightly higher, as is the transmittance of its façade. Although case 5 has roof insulation, its effects are minimised when the whole block is analysed, as the percentage of roof to façade is very low. In cases 2 and 3, the least severe in winter (letter A), heating demand is also more than double that of the limits set in the CTE, highlighting that the energy behaviour of social housing stock in the south of Spain in general is highly deficient.

The cooling demand values are closer to the limit of the values stipulated in the CTE (Fig. 8, Table 3), slightly exceeding them in cases 1, 3 and 5, located in the most severe summer climate zones (catalogued under number 4).

The poor thermal performance of the envelope and the lack of thermal systems with suitable energy performance translates into an estimated consumption (based on the CTE standard usage and operation conditions), which almost triples the limit of values required by the CTE (Fig. 9, Table 3). In case 5, with the most severe regional climate both in winter and summer (climate zone C4), estimated consumption exceeds 190 kWh/m^2.

In addition, this entails the estimation of high levels of CO_2 emissions (Table 3), which translate into energy rating E, in the lower bands of the scale established by the CTE (which goes from A, the best rating, to G, the worst). This situation, found in a high percentage of the social housing stock in the south of Spain, is still far from reaching the goals established by Horizon 2020, reflecting an urgent need for energy retrofitting of this housing stock.

Table 2. Morphological indicators.

	Case 1 (Seville)	Case 2 (Malaga)	Case 3 (Huelva)	Case 4 (Granada)	Case 5 (Jaén)
% roof in the envelope	16.6	13.8	19.9	19.3	12.3
% façade in the envelope	67.0	72.5	60.3	61.4	75.4
% opening in the façade	10.9	18.4	22.9	15.5	17.1
Form ratio (envelope surface/volume) (m^{-1})	0.42	0.27	0.32	0.40	0.41

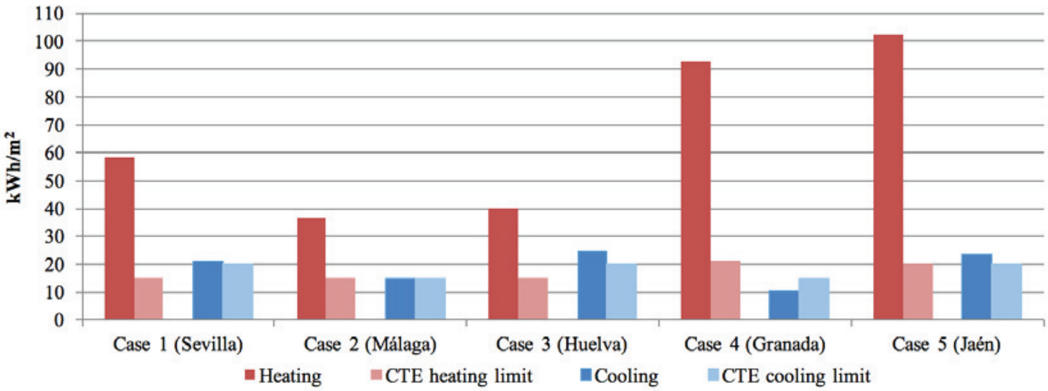

Fig. 8. Heating and cooling demands.

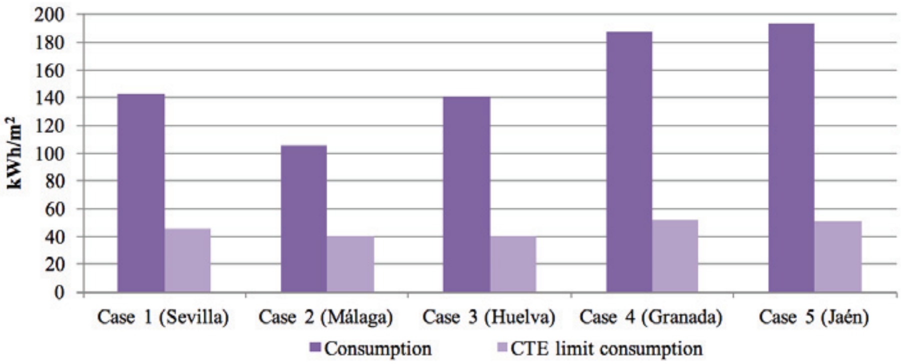

Fig. 9. Estimated consumption.

Table 3. Results: demand, consumption, energy rating and CO2 emissions.

	Case 1 (Seville)	Case 2 (Malaga)	Case 3 (Huelva)	Case 4 (Granada)	Case 5 (Jaén)
Climate zone	B4	A3	A4	C3	C4
Heating demand (kWh/m^2)	58.3	36.7	39.8	92.7	102.6
CTE heating limit demand (kWh/m^2)	15	15	15	21	20.4
Cooling demand (kWh/m^2)	20.9	14.8	24.4	10.1	23.4
CTE cooling limit demand (kWh/m^2)	20	15	20	15	20
Consumption (kWh/m^2)	143.0	105.2	141.2	186.8	193.8
CTE limit consumption (kWh/m^2)	45.8	40.4	40.9	51.4	50.7
Energy rating	E	E	E	E	E
CO_2 emissions (kg CO_2 / m²)	29.4	21.7	28.9	39.1	40.1

5. Conclusions

A high percentage of social housing stock in southern Europe is obsolete in terms of energy and needs retrofitting in order to fulfil the objectives of Horizon 2020. Prior to this retrofitting an energy characterisation, with a specific methodology designed to facilitate this task, should be carried out on the housing stock. This research proposes an assessment protocol for social housing stock in the south of Europe, with the first phase applied specifically to five case studies in southern Spain.

The protocol defined distinguishes between two levels of assessment for the energy behaviour of social housing stock: a general one with four tasks which analyse statistics and context, as well as energy demand and consumption, at a general residential complex level (phase 1); and another detailed one with four tasks including onsite measurements of hygrothermal behaviour and energy consumption, the generation and validation of detailed energy models and the assessment of the results, applied to individual housing units (phase 2). Once completed, these tasks can provide us with a complete assessment of the end-use energy behaviour of housing stock in the south of Europe.

The protocol includes the use of GIS platforms to upload the data collected and results obtained during phase 1, which is essential for continuously expanding and updating information in different workgroups, guaranteeing the application of the established protocol.

The application of the first phase of the protocol to five case studies in the south of Spain for a general assessment of energy behaviour led to the following conclusions:

- It was established that between 1950 and 1980 a social housing complex model with very similar typological, morphological and constructive features was frequently reproduced in the different climate zones of the south of Spain. This is why all case studies exhibit a similar thermal behaviour pattern, varying according to the severity of the climate zone they are found in.
- Heating demand ranges from 2.4 (zone A) to 5 times (zone C) the limits established in the Spanish Technical Building Code.
- The estimated energy consumption of the cases analysed ranges from 2.6 (zone A3) to 3.8 times (zone C4) the limits established in the CTE.
- An E energy rating was obtained, within the lower limits of the established scale.

Therefore, in pre-1980s social housing in the south of Spain there is generally a high level of demand due to the poor thermal performance of the envelope, which has no insulation whatsoever. This translates into habitability conditions in dwellings far below current comfort standards, as poor thermal behaviour requires high energy consumption in order to satisfy current indoor comfort demands for dwellings. These are not within the economic reach of residents in these social neighbourhoods, who run the risk of energy poverty. It is therefore essential to implement actions to improve energy behaviour in retrofitting programmes for the housing stock built in this period.

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